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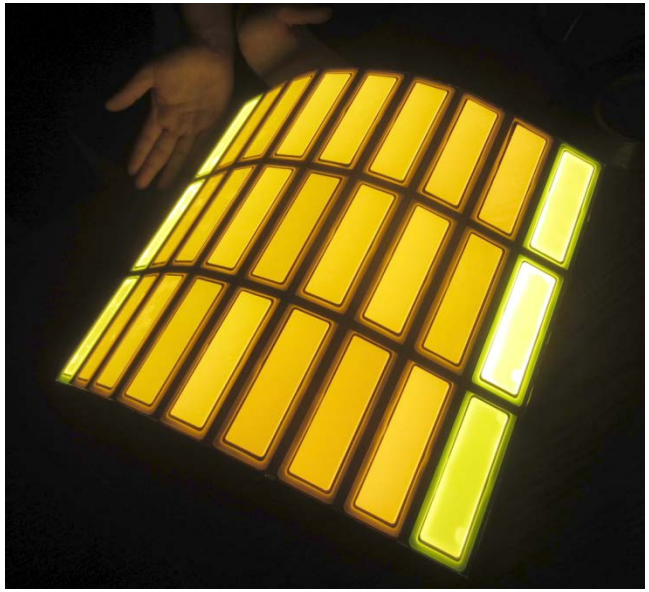
U.S. OLED Lighting Manufacturing Status and Trends

John W. Hamer
OLEDWorks LLC



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OLEDWorks Introduction

- We are the only US manufacturer of OLED lighting panels.
- Founded in Rochester NY in 2010
- Focused exclusively on OLED lighting and its benefits
  - Thin
  - Light weight
  - Low temperature
  - High efficiency, now and future potential
  - Solid state benefits including easy integration of drivers and controls
  - Specialty features - transparent, flexible, color changing, …
- Our first product is a maker light for health care applications.
- Larger panels will be shown at Lightfair.

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OLEDWorks Introduction

- 22 full-time OLED experts
  - Over 200 years of combined OLED experience
  - Experience across all areas of OLED technology
- Acquired equipment and set up of state of the art OLED R&D facility
- Design and startup of novel, flexible, scalable OLED production facility.
- Production of our first product has started.
- We work with many partners:
  - Suppliers to the OLED lighting industry
  - Downstream luminaire partners.

OLEDWorks Research and Development lab

One of four research OLED deposition coaters

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If I had $100M to build a large OLED lighting manufacturing plant, would I build it in the US?

Disadvantages

- OLED industry concentration is in Asia, focused on displays.
- Majority of industry suppliers are overseas
  - Equipment suppliers
  - Substrates suppliers
  - Encapsulation suppliers
  - OLED materials suppliers
- "Technology commons" for OLED in US is thinning
  - University, Gov't research
  - Supporting industries (e.g. thin film)

Advantages

- OLED expertise critical mass is here. This is a huge factor.
- Luminaire customers want custom products and easy communications.
- Low-skill labor is only a minor part of Cost of Goods Sold.
- US is very competitive in R&D, and for industry success we rely on innovation for reduced costs and higher performance through:
  - Equipment
  - Processes
  - Materials

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Current State of OLED Lighting Manufacturing in US

Our experience for early products, which uses conventional substrates, tandem OLED structures, and traditional encapsulation:

Category	Attributes	Today	Reason
Equipment	Custom	US - partnership	We needed innovations in manufacturing processes and equipment in order to succeed as a start-up with limited funding.
Substrates	Standard	US supply - probably Asia source	We need low cost, but we are small volume.
OLED Materials	Standard	Worldwide	We require competitive performance. We seek the latest improvements.
Encapsulation Materials	Standard	Non-US	Highest performance, lowest cost.
	Custom	US - partnership	World class skill, great partnership.

- **Summary** - For custom solutions, US partnerships offer tremendous advantages.

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Importance of Partnerships - Models for Progress in OLED Lighting Mfg

- Solutions to OLED lighting challenges are muliti-disciplinary:
  - For example - developing a new material/process/machine using advances from adjacent fields
    - Technology breadth of solutions often requires partnerships.
  - Development is faster and the results are better with partnerships.
    - Both parties benefit - Shared risks, shared rewards.
- Partnerships are facilitated locally
  - The “Technology Commons” – interaction on many levels
  - For smaller companies – collaboration can be easier
    - They need to pool resources – and often seek critical DOE funding
    - They are driven to succeed – willing to take risks, move faster
    - View that “a share of something bigger” is better than “all of something unknown”

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Increasing OLED Lighting Manufacturing in the US - Proposal

1. Strategy – focus on growing the OLED lighting panel manufacturing industry here in the US – we need several companies manufacturing.
   - If the US loses this, the supporting component industries will diminish or leave the US to be near their customers.
     - Substrates, anodes, light extraction
     - Organic materials
     - Encapsulation materials and methods
2. The key in panel manufacturing is deposition operations – **both**:
   - Vacuum Thermal Evaporation, **and**
   - Solution Processing
3. The critical partnership is panel manufacturer and deposition equipment maker
   - Supporting and developing this technology partnerships here is required for success
4. The US can win at this – and have a strong OLED lighting manufacturing industry.
   - This will facilitate success of supporting component industries.

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Future OLED Lighting - Will it be Vacuum Thermal Evaporation?

- The current vacuum thermal evaporation equipment is too expensive.
  - The Sunic G5 machine is predicted to have a depreciation of approx $100-200/m2 (5 year depreciation at capacity).
  - The Cost of Goods Sold total target is $100/m2 for OLED lighting to have high volumes (achieve $80/klm and compete in general lighting).
  - Alternative approaches with lower capital cost must be developed.
- Machines must be developed enabling businesses to make profits while the market grows.
  - Today's VTE machines require business losses until machine is producing at capacity – and maybe beyond.

- Extra Challenge - It is difficult for US equipment companies to enter the foreign marketplace – even with a better product.
  - Strong partnerships already exit between foreign OLED makers and their equipment suppliers.
  - Decisions favor the local suppliers – often due to gov't support – not a level playing field.
  - Applied Materials and Veeco appear to have stepped back.

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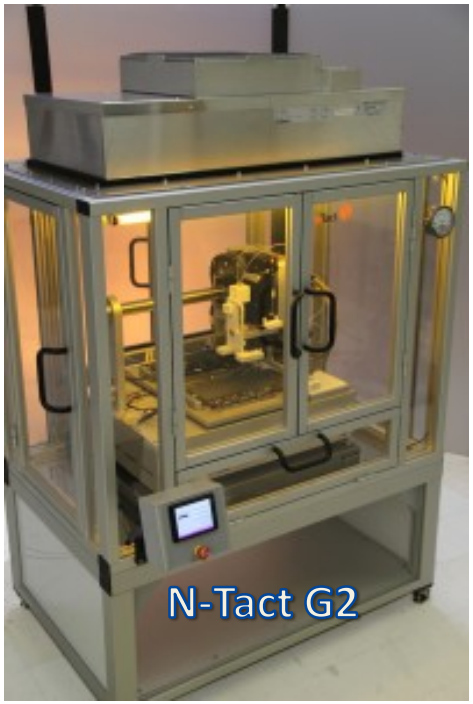
Future OLED Lighting - Will it be Solution Deposition?

- Solution deposition has a good cost structure
  - Machine throughput can be very large
- The depreciation costs are still high.
  - Konica Minolta - $100M for 1M panels/month capacity (assume post yield and post substrate usage)
  - Product is 150x60mm (smaller size 50x30mm)
  - Deprecation is $185/m2 (5 year depreciation at capacity)
  - Alternative approaches with lower capital cost must be developed.
- Solution based formulations currently have lower performance
  - The number of layers and degree of control is less than with vacuum thermal evaporation
- The US has many companies with solution/solvent deposition capabilities
  - This technology will likely be the low-cost route.
  - GE appears to have stepped back, Kateeva is targeting displays.


Konica Minolta solution deposition line


N-Tact G2

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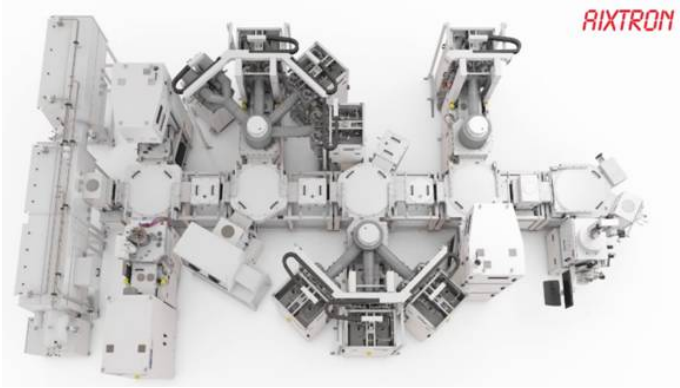
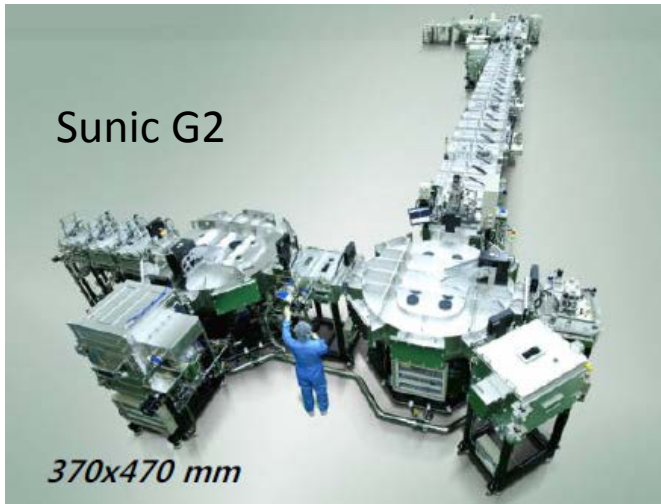
Increasing OLED Lighting Manufacturing in the US – *How to make progress in deposition*

- Desirable attributes:
  - **Small and fast equipment**
  - Lower initial cost with low capacity
  - Ability to expand capacity with reuse of capital
- Focus on speeding up processing to get capacity
  - We must understand the speed barriers and how we can overcome these.
- Expandable with incremental investment:
  - Small initial size – multi function
  - Expansion by duplication and debottlenecking
  - Capacity increase by substrate speed increase
- Lighting does not need large-area substrates – unlike OLED displays





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Why the US can Win at the Deposition Equipment Business

- There are interactions between:
  - Formulation and equipment
  - Process conditions and device performance
- The US can develop this equipment – we have this knowhow .
- We need partnerships between OLED makers and equipment makers and government.
  - Look at the German and Korean models

- The investment will be worth the risk.
- In 10 years, WW OLED lighting volumes may be 10M m2/year with 20% CAGR (~5% of lighting market)
  - This could be 30-50 fast machines.
    - With 8 new machines/year
- The US should aim to dominate this manufacturing industry.
  - Other countries have the same target.

Will the future look like this?

Or this?

Or something completely different?

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Summary – Jobs of the Future in OLED Lighting

- Focus on improving deposition technology:
  - Small, fast, expandable, cost effective, flexible, profitable
  - There is a long way to go. Current equipment models for success don't work.
  - Develop both VTE and solution deposition systems.
- Target partnerships to develop improved OLED deposition technology and *use it in panel manufacturing*
  - Primary Partnerships - OLED makers and equipment makers to expand panel manufacturing
  - Enable small profitable panel mfg operations through improved process and equipment by leveraging an understanding of the interactions between product and process
- Require all projects to achieve DOE milestones to enter general lighting
- We can grow the OLED lighting manufacturing industry here in the US.
- "OLED Lighting - If we aren't nimble, the future is dim"
  - Dave Gotthold, Veeco, DOE Mfg Workshop, Boston, Mar 2011

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